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Procedia - Social and Behavioral Sciences 97 (2013) 325 – 332

Procedia
Social and Behavioral Sciences

The 9th International Conference on Cognitive Science

Do students need more motivational resources or more cognitive resources for better learning?

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Abstract

A cognitive learning task can impose a harmful load on the working memory capacity of learners. This load stems either from the intrinsic difficulty or instructional format of the task. Better learning requires optimizing the load or avoidance of exceeding the capacity. Reviewed literature suggests tailoring an instructional design to learners' expertise levels. However, the allocation of the available capacity to the learning calls upon learners' motivation. Whether students draw upon more cognitive resources or more motivational resources is not clear enough. This review explains the need for further examination of how an instructional intervention must be tailored not just to suit the expertise levels, but also to meet learners' motivational needs.

Selection and/or peer-review under responsibility of the Universiti Malaysia Sarawak.

Keywords: working memory; cognitive load; cognitive effort; motivation; expertise level

1. Introduction

One of the most addressed issues in educational and psychological literature is concerned with the effect of working memory limitations (capacity and duration) on human (conscious) learning and performance of a cognitive task. An expanding body of the literature suggests that if the limited capacity is exceeded or exposed to an intrinsic or extraneous cognitive load, the learning (i.e., the construction or reformation of cognitive schemata) will be hampered [1]. To facilitate the learning, an instructional intervention should be aimed at optimizing the cognitive load as well as freeing up cognitive capacity. This suggestion is congruent with "cognitive load theory" proposed by Sweller et al. [2]. Sweller [1] stated that: "The allocation of working memory resources to deal with intrinsic cognitive load, concerned with the intrinsic complexity of information; extraneous cognitive load, concerned with the manner in which instruction is designed; and germane cognitive load, concerned with the acquisition of knowledge has been an important facet of cognitive load theory for some time" (p. 123). The theory proposes tailoring an instructional design to students' expertise levels (i.e., lower or higher level of prior domain-specific knowledge about a given cognitive learning task) as the most effective way to promote the learning [3].

However the control over the cognitive load is facilitatory to the learning, the use of available cognitive resources (time and capacity) is the main determinant of better learning and performance of a cognitive task [4]. A growing consensus among the literature, such as Moreno [5], Paas et al. [6], Schnotz [7], Schnotz and Kürschner [8], and Van Merriënboer and Sweller [9], concerning the theory suggests the need for motivation, encouraging students

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Selection and/or peer-review under responsibility of the Universiti Malaysia Sarawak.
doi:10.1016/j.sbspro.2013.10.241

to devote the available resources to the learning. Unless students are motivated, the control cannot sufficiently help students apply the resources. This raises the question of how students devote the cognitive effort/resource to the learning. As De Jong [10] noted, the extent to which motivation is a determinant of working memory function is an unclear issue, which needs further studies.

This review aims to present a critical discussion about some boundaries of the cognitive load theory. The review mainly addresses the two issues: first, how to control cognitive load through an instructional design, and second, how to motivate students to allocate the necessary cognitive effort. The discussion expounds the reasons to bring these issues into further studies, suggesting a further examination of cognitive and motivational determinants of an effective instructional design. The theory would hereby provide a new insight into the issue of how to optimize the use of working memory.

2. Cognitive Load Theory

Human (conscious) learning is subject to the limitation of working memory in capacity as well as in duration. According to Baddeley [11] and Cowan [12], working memory is capable of operating two-to-four of chunks of novel information that is lost after about twenty seconds, if it is not rehearsed intentionally. Hence, if the working memory receives an excessive amount of novel information, its capacity will be overloaded. This situation is called "cognitive overload" hampering the learning. To remedy the situation, cognitive load theory [2] aims ''to provide guidelines intended to assist in the presentation of information in a manner that encourages learner activities that optimize intellectual performance" (p. 25).

The theory mainly focuses on the development of an effective instructional intervention (guidance, aid, or design), which requires less cognitive effort and less training time for the construction of cognitive schemata. According to the theory [13], learning occurs best when the intervention is tailored to the cognitive architecture of students. Designing verbal (spoken and written text) and pictorial (illustrations, photos, animation, or video) elements of a cognitive learning task with respect to working memory capacity allows the manipulation of traditionally three separate, but additive, cognitive loads , namely, intrinsic, extraneous, and germane. De Jong [10] explained that "one might say that intrinsic and extraneous cognitive load concern cognitive activities that must unavoidably be performed, so they fall under cognitive load; the germane cognitive load is the space that is left over that the learner can decide how to use, so this can be labelled as cognitive effort" (p. 113).

2.1. Intrinsic cognitive load

Cognitive learning tasks, which are intrinsically difficult or complex, impose the intrinsic load on working memory capacity of students. A cognitive task is considered difficult if it requires simultaneously learning a large number of instructional elements, which are highly interacting. Sweller [1] considered an element to be "anything that needs to be or has been learned, such as a concept or a procedure" (p. 123). For example, learning grammatical syntax, concepts, or procedures is more difficult than learning individual words independently of one another. However, not only the amount of elements or the level of element interactivity, but also the characteristic of information elements determines the level of the load. Learning some information can intrinsically be more difficult than the others [14]. For example, learning of abstract concepts is more difficult than the learning of concrete concepts.

The intrinsic load can be altered by an instructional design or manipulation in several ways: (a) by sequencing the interacting elements in a simple-to-complex order, preventing students from experiencing the full complexity of the interaction [15]; (a) by isolating highly interacting elements (the isolated-interacting elements effect), allowing students to learn what individual elements are before learning how all the elements interact [16]; (c) molar worked-out examples, directing students' attention to problem categories and category-specific solution procedures to learn, and (b) by modular worked-out examples, directing students' attention to an individual problem category and its modular solution steps to learn [17]. These ways can be effective to reduce the load as long as they allow students to use the available cognitive capacity for learning, but not for processing the extraneous cognitive load.

2.2. Extraneous cognitive load

The extraneous load is mainly associated with modality [18], redundancy, and split-attention effects [19]. Students are exposed (a) to the "modality effect" when they simultaneously receive various textual and pictorial information elements through only the visual modality; (b) to the "redundancy effect" when they are presented with a unneeded spatial combination of the information elements, such as the combination of a text with a diagram, which is intelligible in isolation; and (c) to the "split-attention effect" when they are presented with an unintelligible diagram, which is spatially segregated from its textual explanations, searching for corresponding parts of the diagram while paying attention to the texts. To reduce the load, Moreno and Mayer [20] suggested, delivering instructional materials over audio-visual modality, respectively excluding the redundant information, and respectively synchronizing the audio-visual information in time and space.

2.3. Germane cognitive load

Van Merriënboer et al. [21] highlighted that the aim of an instructional intervention is not only to control the extraneous or intrinsic load, but also to free up cognitive capacity and allow students to allocate it to processing germane cognitive load. Schnotz and Kürschner [8] argued that what qualifies a cognitive load as germane is conscious learning/processing because it requires the devotion of cognitive effort. Otherwise, the germane load would not be different from the intrinsic and extraneous load in the sense of occupying working memory capacity without significant contribution the learning.

2.4. Distinguishing between the intrinsic, extraneous, and germane cognitive loads

An instructional design aiming at reducing the extraneous load to prevent students from spending their available time and cognitive capacity in processing information that are not germane to the learning, can obstruct the germane learning process itself [13]. Instructional messages, such as example comparison and elaboration, which are regarded as redundant, can be contributory to the learning. Mayer and Johnson [22] remarked that the learning can be hampered if the supposedly redundant information is removed.

According to De Jong [10], particularly less experienced students are exposed to the intrinsic and germane loads at the same time when they select, organize, and integrate verbal and pictorial information elements with existing knowledge structures, engaging in "essential processing" (i.e., mentally selecting new information) and "generative processing" (i.e., mentally organizing novel information into coherent cognitive schemata). Kalyuga [4] suggested regarding the germane load as identical to the intrinsic load because there is no specific empirical evidence for the germane load. Sweller [1] proposed using the germane load concept to emphasize the amount of cognitive resources devoted to the learning rather than the amount of the intrinsic load.

In consequence, cognitive load only consists of the intrinsic and extraneous loads. Kalyuga [4] and Sweller [1] suggested further studies which are aimed at developing a precise measurement to differentiate only between the two loads. In the absence of such a measurement, levels of student expertise can be considered a traditional way to distinguish between the loads [23].

2.5. Levels of learner expertise

Kalyuga and colleagues [3] reviewed the empirical literature on the interaction between instructional techniques and levels of learner experience and concluded that the cognitive loads vary due to "the expertise reversal effect" meaning that "Instructional techniques that are highly effective with inexperienced learners can lose their effectiveness and even have negative consequences when used with more experienced learners" (p. 23). In a series of studies, such as DeLeeuw and Mayer [24], Kalyuga [25], Paas et al. [13], and Van Merriënboer et al. [26], students with relatively higher and lower levels of a cognitive task performance, namely, their expertise levels were considered to differentiate between the extraneous and germane loads. High cognitive load, such as elaborated descriptions for a diagram, was reckoned to be germane as long as it facilitated the acquisition of basic knowledge structures or the reformation of existing schemata, but to be extraneous, when it interfered with or did not contribute to the learning. Moreno and Mayer [20] stated that a diagram can be intelligible to high expertise students without an elaborated text. If the diagram is presented with such a text, the students waste their available time and cognitive capacity by holding mental representation of the text as the extraneous load.

However, the proposition that levels of expertise determine the types of cognitive load seems to be inconsistent with a basic suggestion of the cognitive load theory that a simplified instruction reduces rather than increases cognitive load. As Schnotz [7] argued, how the intrinsic load can become the extraneous load for high expertise students is not sufficiently clear. If the extraneous load happens due to the waste of working memory resources, then it is likely to stem from the total amount of cognitive processing, rather than the number of information elements processed [7]. Such challenges in the detection of a specific boundary between the types of cognitive load, according to students' expertise levels or cognitive task performance, raise the question as to how an instructional design must be aligned with the expertise levels to manipulate the loads.

2.6. Tailoring an instructional design to the levels of student expertise

According to cognitive load theory [2], an instructional design should be aimed at helping students mentally combine various instructional messages into related cognitive schemata, so that they exert less cognitive effort to process the acquired knowledge structures. The working memory capacity does not significantly impede the processing of rehearsed and organized schemata (encoded and classified information units with common features in long-term memory), but the processing of unorganized novel information. As Sweller [27] stated: "Whereas there are severe capacity limits to the amount of information from sensory memory that working memory can process, there are no known limits to the amount of information from long-term memory that can be processed by working memory" (p. 13).

An instructional design, guidance, or aid can render the help as long as it is aligned with the expertise levels. A spatial combination of verbal and pictorial instructional materials is a way of helping low expertise students, while the segregation of the materials is helpful for high expert students [3]. Leung et al. [28] reported that an elaborated text for a mathematical equation improved the learning for less experienced students, but did not improve the learning for relatively advanced students. As students increase their expertise levels, they learn better via only a visual presentation; the integration would be no longer helpful. The visual rather than verbal processing facilitates the construction of mental representations, easing the acquisition of schemata for all the students [18], [29]. Both low and high expertise students learn better from a visual presentation, which is accompanied with verbal explanations as narration rather than as written text. Oral explanations for the static visual materials in a conventional learning environment [2], and spoken text instead of onscreen text for the dynamic visual materials, in a multimedia learning environment, facilitate imagining the content of instruction [30] as well as avoiding the split-attention effect [23].

However, Moreno and Mayer [20] and Schnotz et al. [31] argued that better learning of a cognitive task does not happen in a classroom environment in which students are not motivated to devote the necessary cognitive effort. Only motivated students allocate the effort, their available working memory capacity, for germane learning processes. Moreno and Mayer [20] remarked that "When learners lack motivation they may fail to engage in generative processing even when cognitive capacity is available" (p. 315). This assertion requires further explanation as to how an instructional intervention must be tailored to meet students' needs for the motivation, but not just to suit their expertise levels [32].

3. Tailoring an Instructional Intervention to Students' Needs for Motivation

Moreno [33] and Schnotz [7] highlighted that an instructional design does not necessarily stimulate students to devote the available capacity to the learning. The devotion requires tailoring an instructional intervention to suit the level of learner expertise as well as to meet their motivational needs [8], such as establishing a match between task difficulty level and the expertise level. If students perceive a learning task as too easy or too difficult, they are discouraged to allocate the effort and persist to learn [34]. For instance, when less experienced students learn a cognitive task via its visual presentation without onscreen text, they usually perceive the task as complicated and frustrating, and, therefore, decrease persistency in the learning; in contrast, relatively advanced students perceive the task challenging, and, therefore, invest more cognitive effort and engage in the learning [35].

According to Schnotz and Rasch [36], to both low and high expertise students' learning, an unchallenging task is inhibitory rather than facilitatory. In Schnotz and Rasch's study, animated pictures (illustrated date/time differences, and the earth's rotation around its axis) impaired low expertise students' learning, more than high expertise students' learning because it made the task too easy. Nonetheless, with the help of animated rather than static pictures all the students performed their task better.

Irrespective of expertise levels, allowing students to learn or perform their tasks on their own is argued to be an effective way to learn and perform better. In a series of studies, such as Kalyuga et al. [37, 38], low expertise students were allowed to practice worked-out examples and thereafter perform a difficult task. They hereby learned and performed better. In contrast, high expertise students who were allowed to explore the same task on their own demonstrated better performance.

A similar finding replicated by Cooper et al. [39] indicated that better performance occurred when low expertise students were allowed to understand and remember the task related procedures and concepts through the examples, and when high expertise students were encouraged to imagine (i.e., the imagination effect) the procedures and the content of concepts. Such imagination effect was also reported, by Leahy and Sweller [40], that the examples rather than the imagination helped low expertise students' learning of a procedure (learning to use a bus timetable). A reversed result was attained when their expertise increased.

Another series of studies found that, for all the students, the examples were helpful, when they were stimulated to give rational explanations (i.e., self-explanation effect), oral [41] and written [42], about what steps were needed to solve a problem [43], [44]. In addition, Van Gog et al. [45] reported that encouraging advanced students to engage in learning-practice activities deliberately (i.e., the deliberate practice effect) improved their learning performance.

However, Renkl [46] argued that merely studying the examples does not assure students of avoiding the misunderstanding of examples; thus, not assuring the construction of coherent knowledge structures. Catrambone and Holyoak [47] additionally maintained that students may be unable to identify how the examples are relevant to a given task, such as problem-solving, or apply the same problem-solving steps to new problems. Schnotz and colleagues [31] laid particular stress on the need for motivation and contended that the examples are not motivating enough, but can be perceived dull and unchallenging. Moreno [44] suggested further studies on the relation of motivation with the allocation of the necessary cognitive effort to explain the reasons for the different effects of worked-out examples on low and high expertise students.

3.1. Do students need motivational resources more than cognitive resources for cognitive processing of germane load?

Motivational factors, such as challenge, anxiety, interest, and probability of success can encourage or discourage students to engage in germane learning processes. In particular, interests and beliefs of students determine the allocation of the necessary cognitive effort [48]. A student having high interest in a learning task would devote more effort than a student with low interest [49], [44]. Paas et al. [6] reported that less cognitive effort was invested when the motivation was lower, indicating lower cognitive performance, but more cognitive resource was invested when the motivation was higher, indicating higher cognitive performance.

According to Elliot and McGregor [50] and Elliot and Thrash [51], the motivational interest can vary according to what students strive for, namely, the achievement goals, which are: (a) "mastery-approach goal" (for the competence in a learning task); (b) "mastery-avoidance goal" (for the avoidance of skill decline, the loss of existing knowledge, or of failures); (c) "performance-approach goal" (for the outperformance of others or for the demonstration of competence; and (d) "performance-avoidance goal" (for the avoidance of appearing incompetent or of doing worse than others). Students striving for the mastery-approach goal devote greater effort to learn [52], unlike those who strive for the performance-approach goal [53].

In addition, if students believe in their competence, they increase or decrease the interest level. Students usually do not invest the necessary cognitive effort unless they believe they can perform a given task successfully [54]. A learner who has such belief usually performs better than the one having low or no belief in the success [55].

Furthermore, students' beliefs in costs of time and cognitive effort, as a waste or a necessity for an achievement goal, can determine the resource investment [56]. The cognitive resources are invested when they believe that the resource expenditure is not a waste, but necessary for an achievement goal [6]. Thus, as Schnotz [7] noted, when students evaluate the investment costs, the evaluation process itself also draws on motivational sources by taking some time and cognitive effort.

The abovementioned suggestions lead to the question of whether cognitive processing, which is conducive to schema construction, calls upon motivational resources rather than cognitive resources. Rey and Buchwald [57] asserted that the available time and working memory capacity rather than motivational factors are essential for the cognitive processing; therefore, the difference between novice and expert students is attributable the cognitive load effect. Rey and Buchwald exhibited that the task performance of novice and expert students was associated with the redundancy effect (i.e., students who are exposed to the redundancy effect and those who are not) rather than the three motivational factors, namely, interest, anxiety, and challenge. This finding also indicated a partial overlap between the effect of "probability of success" and the redundancy effect. Such an overlap is predicted by Schnotz et al. [31], who argued that the rating scale used to measure both the motivational factor and the redundancy effect consists of nearly the same kind of questions, measuring the perceived task difficulty. Hence, as Schnotz [7] contended, "the extraneous load due to a waste of time and effort resulting from irrelevant cognitive processing is essentially a load on a motivational resource rather than a cognitive resource" (p. 318). Therefore, the actual amount of invested motivational resources spent rather than the used amount of cognitive capacity could be the main determinant of students' engagement in germane learning processes [20], [7]. An accurate determination of the main factor requires further studies on the relation of motivational factors with the allocation of the necessary cognitive effort.

4. Conclusion

This review has reconsidered the main concern of the cognitive load theory, the issue of how to optimize students' use of working memory to enhance their learning and performance of a cognitive task. This reconsideration has concluded that the theory can be more effectively applied to an instructional intervention, provided that it concerns itself with the motivational resources of students, but not only with the cognitive resources or the optimization of cognitive load. Such a consideration would facilitate the prediction of what influence different motivational factors will exert on the allocation of cognitive effort to the learning and task performance.

The review has, therefore, specifically explicated the need for further investigations into the relation of motivational factors with the optimal use of cognitive capacity. An instructional design, guidance, or aid should be tailored to students' expertise levels and motivational needs in a mutually inclusive manner. Further studies are needed to explain how this suggestion can be realized.

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